

Digitalization of teaching and learning in TVET: a bibliometric analysis

Norazreen Othman, Marlissa Omar, Mohamad Sattar Rasul

Center of STEM Enculturation, Faculty of Education, Universiti Kebangsaan Malaysia, Bangi, Malaysia

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ABSTRACT

The rapid integration of digitalization in technical and vocational education and training (TVET) has gathered significant attention from researchers worldwide. This research conducted a comprehensive bibliometric analysis to explore the current landscape of digitalization of teaching and learning in TVET. The aims were to identify research trends, the most cited articles, type of document by subject area, top 10 authors, research hotspot, co-authorship analysis, and citation of article's density. Bibliometric analysis techniques were employed by examining publication data spanning from 2015 to 2023, extracted from the Scopus database, particularly focusing on network visualization and clustering methods using VOSviewer software. The analysis revealed a steady increase in research output over the past decade, indicative of growing interest in the field. The distribution of publications among authors was balanced, indicating a collaborative research landscape. Nonetheless, there were swings in publishing rates, indicating the dynamic character of research goals and trends. Moreover, subject area analysis demonstrated a multidisciplinary approach reflecting the multifaceted nature of digitalization in TVET. By leveraging bibliometric analysis techniques, this research contributes to a deeper understanding of research trends, guiding future research directions and to advance innovative and sustainable practices in digital teaching and learning within TVET, thus benefiting learners, educators, and stakeholders.

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Corresponding Author:

Marlissa Omar

Centre of STEM Enculturation, Faculty of Education, Universiti Kebangsaan Malaysia

Bangi, Malaysia

Email: marlissa@ukm.edu.my

1. INTRODUCTION

Integrating digital technologies into technical and vocational education and training (TVET) indicates a transformative shift in teaching and learning methodologies. It aims to enrich educational experiences and equip learners with essential skills for the modern workforce [1]–[5]. Diverse digitalization practices emerge within the TVET landscape, from blended learning to the flipped classroom model, each demonstrating efficacy in enhancing student engagement and achievement [6]–[9]. Furthermore, the positive impact of digital intelligence technologies in teaching emphasizes improvements in student motivation and performance [10]. However, challenges such as selecting appropriate digital resources and software integration persist, exploring the digital transformation of educational systems amidst the COVID-19 pandemic [11]. The integration signifies a revolutionary change intended to enrich educational experiences and equip learners for contemporary workplaces. Despite the effectiveness of diverse digitalization strategies in enhancing student engagement and academic achievements, persistent challenges, notably in selecting and integrating digital resources, are highlighted by the digital overhaul of educational systems during the COVID-19 pandemic.

The digitalization of teaching and learning in TVET interprets a pioneering approach to integrate digital technologies. At its core, digitalization encourages a holistic digital transformation of TVET pedagogy, leveraging state-of-the-art tools and methodologies to transform the teaching and learning process [12]. Central to this is the incorporation of interactive multimedia resources, virtual simulations, and online platforms, all tailored to enhance student engagement and facilitate practical skill acquisition [13]–[16]. Thus, by embracing digitalization, TVET institutions can transcend traditional boundaries of time and space, offering learners flexible learning opportunities that align with the demands of a rapidly evolving job market [7]. Moreover, digitalization emphasizes the importance of continuous professional development for educators, ensuring they possess the requisite digital competencies to leverage these technologies in their instructional practices effectively [17]–[20]. In addition, digital technologies integrated into TVET signify a transformative shift, aiming to enhance student engagement and facilitate practical skill acquisition. Through continuous professional development for educators, digitalization enables TVET institutions to transcend traditional boundaries and align with the evolving demands of the modern job market.

Hence, broader societal implications of digitalization in TVET, particularly in terms of addressing skill gaps and raising economic competitiveness [21]. By equipping students with brand-new digital skills and competencies, TVET programmes can better align with industry needs and equip graduates with the tools to thrive in a digital economy [22]–[24]. Additionally, digitalization opens opportunities for collaboration between TVET institutions, industry partners, and policymakers, nurturing a synergistic ecosystem that promotes innovation and knowledge exchange [25]. Therefore, it encourages for a collaborative effort and ensures that all learners can benefit from the transformative potential of digitalization in TVET [25], [26]. The widespread adoption of digitalization in TVET holds significant societal implications, particularly in addressing skill gaps and fostering economic competitiveness. By equipping students with advanced digital skills, TVET programmes can better align with industry needs and prepare graduates for success in a digital economy. Furthermore, digitalization promotes collaboration between TVET institutions, industry partners, and policymakers, nurturing an ecosystem of innovation and knowledge exchange. It underscores the importance of collaborative efforts to ensure that all learners can harness the transformative potential of digitalization in TVET.

Through comprehensive digitalization, it can catalyze a paradigm shift in TVET education, empowering learners with the skills and competencies required to succeed in the digital age [17], [27], [28]. Thus, the research aims to provide a comprehensive exploration, a pioneering approach that integrates digital technologies into TVET by exploring the year-wise trends, citation patterns, and document types. The research explains the evolving landscape of digitalization within TVET. Moreover, it aspired to recognize the most influential authors while uncovering prevalent keywords that capture the thematic essence of the literature. The research also aims to investigate the geographic distribution of research contributions and the cooperation networks among nations, providing insight into the global dynamics of TVET digitalization. These are the aims of the research: i) to identify trends for the digitalization of teaching and learning in TVET according to the year of publication; ii) to find out the type of document by subject area of the research; iii) to figure out the research hotspot by keyword; iv) to recognize the most cited articles about the digitalization of teaching and learning in TVET; v) to determine the top ten authors based on citation by research for digitalization of teaching and learning in TVET; vi) to conduct a co-authorship analysis; and vii) to discover the citation of the article's density by country.

2. METHOD

Combining, organizing, and analyzing bibliographic data from scientific publications is known as bibliometrics [29]–[32]. It includes intricate methods like document co-citation analysis in addition to general descriptive statistics like publishing journals, publication year, and major author categorization [33]. To create a thorough bibliography and produce reliable results, a successful literature review requires an iterative process that includes selecting relevant keywords, searching the literature, and doing in-depth analysis [34]. Considering this, the research aimed to concentrate on high-caliber publications since they provide insightful information regarding the theoretical stances influencing the development of the field of research. The Scopus database was utilized by the research to collect data in order to guarantee data reliability [35], [36]. Furthermore, books and lecture notes were purposefully excluded in order to guarantee the inclusion of high-caliber publications. Notably, only articles published in thoroughly peer-reviewed academic journals were considered [37].

Scopus was selected for this research since the database is renowned for its comprehensive coverage of scientific literature, encompassing peer-reviewed journals, conference proceedings, and books across diverse disciplines. Its extensive scope ensures that researchers have access to a wide array of scholarly sources. One of its key advantages lies in citation analysis, enabling researchers to gauge the impact of their work and

identify influential research trends. Additionally, Scopus offers author profiles that compile publication history, citation metrics, and collaboration networks, enhancing researchers' visibility and facilitating networking. Its advanced search functionality allows for precise retrieval of relevant literature based on various criteria, while visualization tools like affiliation mapping help analyze collaboration networks and research trends. Furthermore, Scopus incorporates altimetric, providing insights into the social impact of research beyond academic citations. Overall, Scopus serves as an invaluable platform for academic research, offering access to literature, tools for impact assessment, and opportunities for collaboration and networking.

2.1. Data search strategy

This research employed a screening sequence with the search terms “digital,” AND “teaching,” AND “learning,” AND “vocational,” AND “education” to determine the search terms for article retrieval. The research was initiated by querying the Scopus database online and assembling 6,003 articles. Afterward, the query string was revised so that the search terms with limitations on document type, literature type, subject area, language, and timeline should focus on the digitalization of teaching and learning in TVET from 2015 to 2024. The final search string, as provided in Table 1, refinement included 1,571 articles used for bibliometric analysis. As of February 2024, all articles from the Scopus database relating to the topic were incorporated into the research.

Figure 1 illustrates the systematic process of selecting articles for the research. Initially, a comprehensive search was conducted in the Scopus database, yielding a total of 6,003 documents. Following this, screening was performed based on predefined inclusion criteria, resulting in 1,571 documents meeting the criteria for further evaluation, while 4,432 documents were excluded. Subsequently, the eligibility of these 1,571 documents was assessed based on their publication abstracts. Ultimately, all 1,571 eligible documents were included in the quantitative bibliometric analysis, forming the basis of this study's empirical investigation into digitalization of teaching and learning in TVET. This systematic approach ensures transparency in the selection of articles, thereby enhancing the reliability and validity of the findings derived from this research effort.

Table 1. The search string

Database	Search string
Scopus	TITLE-ABS-KEY (digital* AND teaching AND learning AND (skills OR technical OR vocational) AND (education OR training)) AND (LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2024)) AND (LIMIT-TO (SUBJAREA, "SOCT")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "English"))

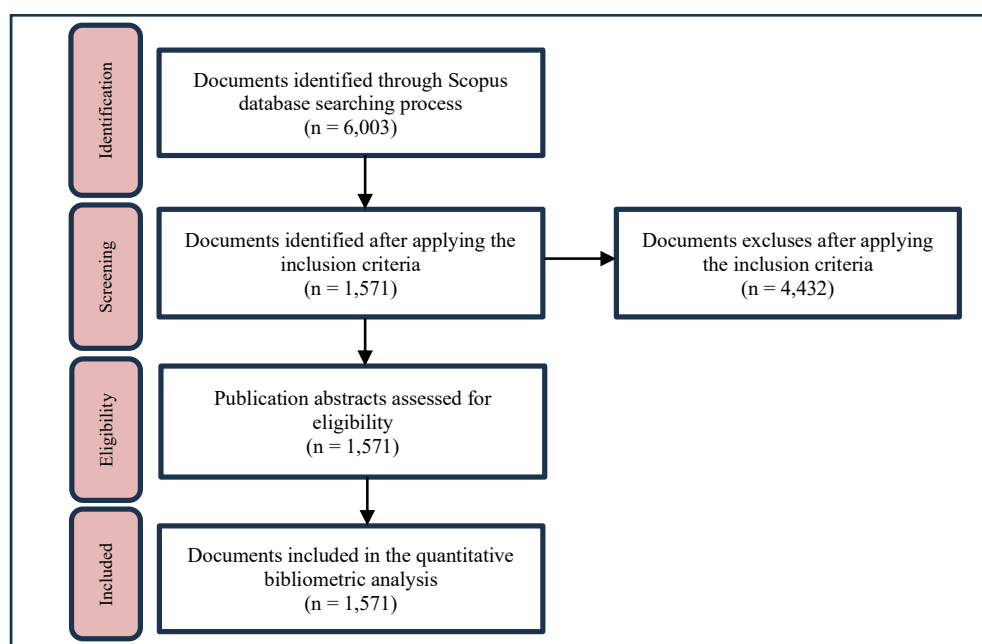


Figure 1. Process of selecting articles for the research

Table 2 provides an overview of the selection criteria applied during the literature search process for this study. Articles were included if they were written in English and published between 2015 and 2024, ensuring relevance to current research trends. Excluded were non-English articles, those published before 2015, and documents that did not fall within the subject area of Social Sciences. Additionally, only articles categorized as journal articles and conference proceedings were considered for inclusion, excluding other document types to maintain consistency in the analysis.

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2015–2024	<2015
Subject area	Social Sciences	Others
Document type	Article	Non-article
Literature type	Journal (article) and proceeding	Book, review

2.2. Data analysis

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands, is a user-friendly bibliometric software widely recognized for visualizing and analyzing scientific literature [38]. Specializing in network visualizations, clustering related items, and generating density maps, the tool offers researchers a comprehensive understanding of research landscapes by examining co-authorship, co-citation, and keyword co-occurrence networks. Moreover, its interactive interface and continuous updates ensure efficient exploration of large datasets, making it a valuable resource for scholars seeking insights into complex research domains.

A standout feature of VOSviewer is its capacity to transform intricate bibliometric datasets into visually interpretable maps and charts, particularly focusing on network visualization and clustering-related items [38]. Datasets procured from the Scopus database, spanning the period from 2015 to February 2024, were analyzed using VOSviewer software version 1.6.19 [39]. Through VOS clustering and mapping techniques, the software facilitated the examination and generation of maps, providing an alternative to Multidimensional Scaling (MDS) approaches. While both methods aim to situate items within low-dimensional spaces accurately reflecting their relatedness and similarity, VOSviewer utilizes a method for normalizing co-occurrence frequencies. This includes association strength (AS_{ij}), diverging from MDS approaches primarily in computing similarity metrics like cosine and Jaccard indices [40]. In this respect, VOSviewer is similar to the MDS approach [41]. Diverging from MDS, which primarily engages in the computation of similarity metrics like cosine and Jaccard indices, VOS utilizes a more fitting method for normalizing co-occurrence frequencies such as AS_{ij} , and it is calculated as [40]:

$$AS_{ij} = \frac{C_{ij}}{C_i C_j}$$

3. RESULTS AND DISCUSSION

3.1. Research trends according to the year of publication

Figure 2 is a line graph that suggests the number of documents published in the journal per year from 2015 to February 2024. The journal's publication output varied over the years, with 2023 suggesting the highest number of publications at 387, followed by 2022 with 313 publications. The trend indicates a gradual increase in publications from 2015 to 2023, with fluctuations in certain years, such as 2019 and 2020. The lowest publication count was observed in 2016, with 52 publications, while in 2015, it was 55 publications. Referring to the trend, we expect to have an increasing number of publications towards the end of 2024.

These increasing numbers reflect the evolving research landscape and scholarly contributions in the journal. This is possibly influenced by changes in research priorities, emerging trends, and external factors affecting academic output. Note that there are several possible explanations for this increase. One possibility is that there have been significant technological advancements related to the digitalization of teaching and learning in recent years. This includes the development of new virtual reality and augmented reality tools and the increasing availability of online learning platforms. These advancements may have increased interest in researching and developing digitalization in TVET. There are also emerging trends in the field of TVET that are likely to continue to drive research on digitalization in TVET. This comprises using artificial intelligence in education, the growth of personalized learning, and the increasing importance of data-driven decision-making.

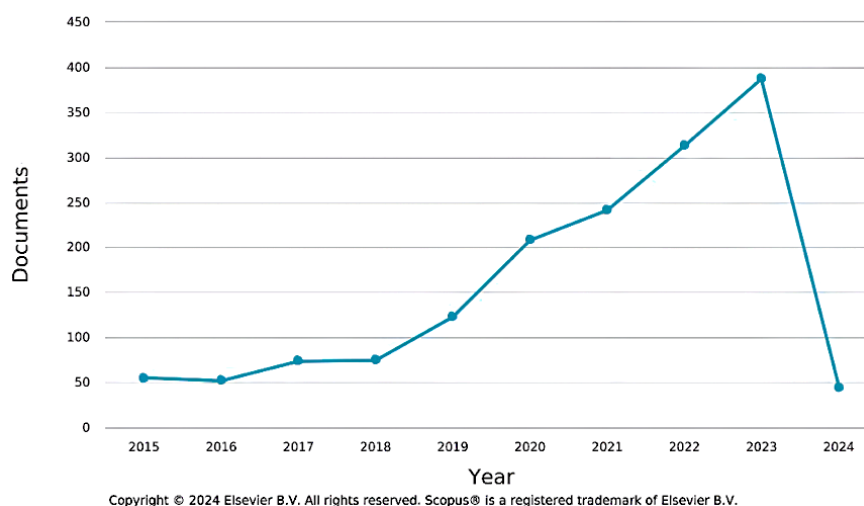


Figure 2. Number of documents published in the journal from 2015 until February 2024

These increasing numbers reflect the evolving research landscape and scholarly contributions in the journal. This is possibly influenced by changes in research priorities, emerging trends, and external factors affecting academic output. Note that there are several possible explanations for this increase. One possibility is that there have been significant technological advancements related to the digitalization of teaching and learning in recent years. This includes the development of new virtual reality and augmented reality tools and the increasing availability of online learning platforms. These advancements may have increased interest in researching and developing digitalization in TVET. There are also emerging trends in the field of TVET that are likely to continue to drive research on digitalization in TVET. This comprises using artificial intelligence in education, the growth of personalized learning, and the increasing importance of data-driven decision-making.

The fluctuations observed in publication output between 2019 and 2020 can be largely attributed to the onset of the COVID-19 pandemic. In 2019, the publication counts likely reflected the typical academic output in the field, with researchers focusing on established topics related to digitalization in TVET. However, the landscape drastically changed in 2020 with the emergence of the pandemic, which prompted a rapid shift towards remote learning and online education globally. This unprecedented transition sparked heightened interest and research activity in exploring the implications of digitalization in TVET within the context of the pandemic. Consequently, the increase in publication output in 2020 can be perceived as a response to the urgent need to address the challenges and opportunities arising from the pandemic's impact on TVET digitalization. Therefore, while fluctuations in publication counts between 2019 and 2020 may seem significant, they primarily reflect the dynamic and evolving nature of research priorities in response to external events such as the COVID-19 pandemic.

3.2. Publication by subject area

Figure 3 presents a comprehensive overview of documents categorized by subject area. Social sciences comprise the majority of publications (52.3%), indicating a strong focus on examining socio-cultural aspects, pedagogical implications, and policy dimensions of digitalization in TVET. However, an interdisciplinary approach is evident, with significant contributions from computer science (14.5%), engineering (5.6%), and arts and humanities (5.3%) reflecting the multifaceted nature of research in this field. Note that fluctuations in publication rates across subject areas may stem from factors like technological advancements, shifts in educational policies, and emerging trends such as sustainability and personalized learning.

The minimal representation of Mathematics, comprising only 1.4% of publications related to the digitalization of teaching and learning in TVET, can be attributed to several factors, such as Mathematics playing a crucial role in various vocational fields. Moreover, its integration into the TVET curriculum and digitalization initiatives may not always be explicitly highlighted or studied as a separate domain.

The results highlight the crucial role of integrating socio-cultural aspects and promoting interdisciplinary cooperation in shaping the digitalization of teaching and learning in TVET. Moving forward, it is imperative for research to maintain this comprehensive perspective, addressing emerging areas to uphold the effectiveness of TVET systems within an increasingly digital landscape. Thus, by embracing these evolving trends and capitalizing on interdisciplinary perspectives, scholars can propel the progress of digital education in vocational settings, fostering innovation and sustainability in educational approaches for the future.

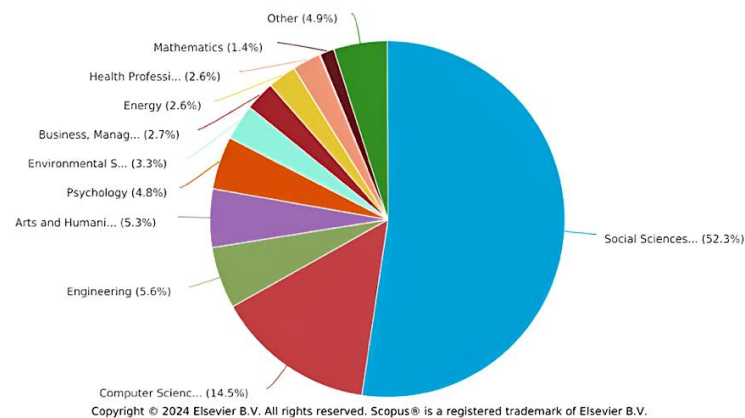


Figure 3. Trend of publication by subject area

3.3. Research hotspots by keywords

Figure 4 is the network visualization map generated by the VOSviewer analyzer, which presents an overview of keyword interrelations concerning the digitalization of teaching and learning in TVET. A comprehensive list of the occurrences and the total link strength are provided in Table 3. Occurrences refer to the number of times a keyword appears in the literature or dataset analyzed. Total link strength, on the other hand, measures the strength of connections or associations between the keywords based on co-occurrence patterns within the dataset.

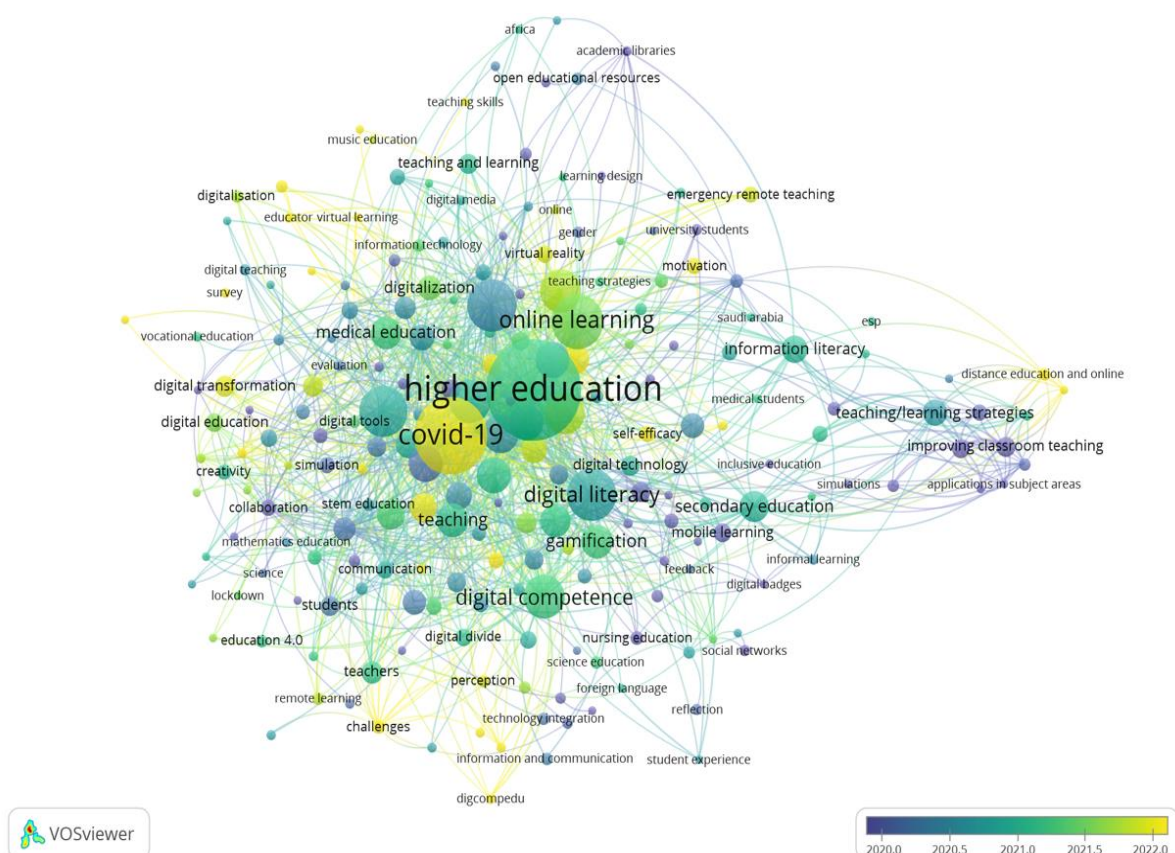


Figure 4. Network visualization map of research hotspot

Table 3. Keyword occurrences and total link strength

Keyword	Occurrences	Total link strength
Higher education	180	393
Covid-19	122	298
Online learning	74	160
Digital literacy	69	168
E-learning	68	154
Education	65	147
Blended learning	52	104
Digital competence	52	111
Digital skills	52	108
Distance learning	49	96
ICT	44	104
Educational technology	40	89
Teacher training	40	92
Technology	40	91
Learning	39	88
Gamification	36	71

“Higher education” has the highest occurrences (180) and a significant total link strength (393), indicating its prominence and strong connections with other keywords in discussions related to digitalization in TVET. “Covid-19” also has high occurrences (122) and a substantial total link strength (298), reflecting the significant impact of the pandemic on teaching and learning practices, especially in digital contexts. Meanwhile, “online learning” with occurrences (74) total link strength (160), “digital literacy” with occurrences (69) total link strength (168), “e-learning” with occurrences (68) total link strength (154), “education” with occurrences (65) total link strength (147), “blended learning” with occurrences (52) total link strength (104), “digital competence” with occurrences (52) total link strength (111), “digital skills” with occurrences (52) total link strength (108), “distance learning” with occurrences (49) total link strength (96), “ICT” with occurrences (44) total link strength (104), “educational technology” with occurrences (40) total link strength (89), and “teacher training” with occurrences (40) total link strength (92), “technology” with occurrences (40) total link strength (91), “learning” with occurrences (39) total link strength (88), “gamification” with occurrences (36) total link strength (71) demonstrate moderate to high occurrences and total link strengths, suggesting their importance and interconnectedness within the domain of digital education. The colors of the network visualization map represent the year of keyword occurrences by year. At the same time, the color scheme denotes chronological progression; blue signifies the year 2020, green represents 2021, and a transition to yellow occurs in 2022.

Based on the analysis, occurrences provide insight into the frequency of specific terms within the literature, indicating their relative importance or prevalence in the field. Total link strength helps identify the strength of relationships between different keywords, highlighting the interconnectedness of concepts and revealing patterns or themes within the research landscape. In addition, analyzing occurrences and total link strength together can provide a comprehensive understanding of the research landscape, including key concepts, their relationships, and their relative importance within the field of digitalization in TVET.

3.4. The most cited articles

A snapshot of research articles focused on the digitalization of teaching and learning spanning diverse themes such as digital literacy, online education, and the impact of technology on pedagogy. In Table 4, the most cited article in the paper by Dwivedi *et al.* [42] with 480 citations, followed by Khalil *et al.* [43] with 426 citations, and Goldie [44] with 266 citations. Meanwhile, other top authors have a number of citations between 112 to 258.

These authors have gathered significant attention and recognition in the field of digitalization of teaching and learning in TVET, as indicated by the number of citations their works have received. Khalil *et al.* [43] conducted qualitative research, and others appear to focus on conceptual frameworks or theoretical discussions. For example, Goldie [44] discussed the connectivism theory. Moreover, there are references to frameworks, perceptions, and analyses, which could imply various research approaches, including experimental, review, or survey articles.

The timeframe of the publications from 2016-2023 suggests a relatively recent focus on the digitalization of teaching and learning in TVET. The influence of the COVID-19 pandemic in 2020 is evident, with several highly cited papers exploring digital readiness, literacy, and the transition to online learning during this period. The emergence of new technologies like generative AI and ChatGPT in 2023 is driving research interest in implications for education. Theoretical frameworks like connectivism and teacher digital competency models aim to establish foundations for integrating digital tools. In addition, papers examine factors influencing ICT adoption and student engagement in online courses, indicating sustained interest in effectively implementing digital technologies.

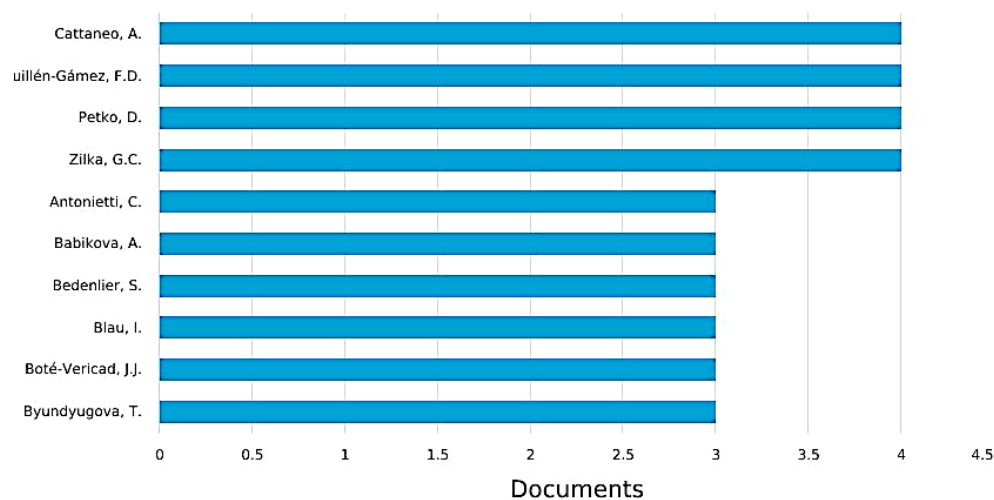
These trends suggest continued exploration of emerging technologies' impacts, comprehensive theoretical framework development, longitudinal studies on digital tools' effects, addressing digital divides and equity in online education, and increasing interdisciplinary collaboration. However, potential implications include a need for ethical considerations, pedagogical approaches for new technologies, understanding long-term learning impacts, promoting inclusive digital access, and addressing complex challenges through holistic, interdisciplinary solutions. The field's development will likely focus on navigating rapid technological change while seeking to harness digital innovations to enhance teaching, learning, and educational outcomes.

Table 4. The most cited articles

Authors	Title	Year	Source Title	Cited by
Dwivedi <i>et al.</i> [42]	"So, what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges, and implications of generative conversational AI for research, practice, and policy	2023	International Journal of Information Management	480
Khalil <i>et al.</i> [43]	The sudden transition to synchronized online learning during the COVID-19 pandemic in Saudi Arabia: a qualitative research exploring medical students' perspectives	2020	BMC Medical Education	426
Goldie [44]	Connectivism: a knowledge learning theory for the digital age?	2016	Medical Teacher	266
Bond <i>et al.</i> [45]	Digital transformation in German higher education: student and teacher perceptions and usage of digital media	2018	International Journal of Educational Technology in Higher Education	258
Falloon [46]	From digital literacy to digital competence: the teacher digital competency (TDC) framework	2020	Educational Technology Research and Development	258
Lawrence and Tar [47]	Factors that influence teachers' adoption and integration of ICT in the teaching/learning process	2018	Educational Media International	163
Phan <i>et al.</i> [48]	Students' patterns of engagement and course performance in a massive open online course	2016	Computers & Education	135
Händel <i>et al.</i> [49]	Digital readiness and its effects on higher education students' socio-emotional perceptions in the context of the COVID-19 pandemic	2020	Journal of Research on Technology in Education	130
Gleason and von Gillern [50]	Digital citizenship with social media: Participatory practices of teaching and learning in secondary education	2018	Educational Technology and Society Publications	122
Tejedor <i>et al.</i> [51]	Digital literacy and higher education during COVID-19 lockdown: Spain, Italy, and Ecuador	2020		112

3.5. Top 10 authors based on citation by research

Figure 5 provides a bar graph of the top 10 prolific authors in this field, along with the number of published documents. The authors with the most publications are Cattaneo, A., Guillén-Gámez, F.D., Petko, D., and Zilka, G.C., with four documents. The remaining authors on the list which are Antonietti, C., Babikova, A., Bedenlier, S., Blau, I., Boté-Vericad, J.J., and Byunduyugova, T. have published three documents each.



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Figure 5. Authors with the most cited articles

Table 5 indicates a balanced distribution of publications among top writers in the field of digitalization of teaching and learning in TVET, with each researcher contributing three or four papers. Interestingly, this fair distribution represents a diversified and cooperative research environment, demonstrating the active participation of several academics in the field's knowledge advancement. With four publications apiece, authors like Cattaneo, A., Guillén-Gámez, F.D., Petko, D., and Zilka G.C., stand out as highly engaged and productive writers. Authors with three publications apiece, authors like Antonietti, C., Babikova, A., Bedenlier, Blau, I., Boté-Vericad, J.J., and Byundyugova, T. have also made noteworthy contributions, underscoring the field's constant level of scholarly activity. Fluctuations in publication rates could be caused by a number of things, including changes in research goals, new trends in digital education for TVET, and technological improvements. However, publication rates may change as more scholars examine the effects of new technology and develop instructional strategies.

Even in the face of these variations, the evenly distributed publications highlight the ongoing interest in and dedication to furthering the field of digital learning for TVET. Future directions could include investigating new trends like personalized learning, tackling concerns of equality and accessibility, and going deeper into how particular digital tools affect student outcomes. Consequently, these patterns emphasize the fluid character of the field's research as well as the chances for continuous innovation and enhancement of teaching methodologies.

Table 5. Authors with the numbers of publications

Author name	Number of publications	Percentages (%)
Cattaneo, A.	4	0.25
Guillén-Gámez, F.D.	4	0.25
Petko, D.	4	0.25
Zilka, G.C.	4	0.25
Antonietti, C.	3	0.19
Babikova, A.	3	0.19
Bedenlier, S.	3	0.19
Blau, I.	3	0.19
Boté-Vericad, J.J.	3	0.19
Byundyugova, T.	3	0.19

3.6. Co-authorship analysis of the research

The map depicted in Figure 6 illustrates an interconnected network within the research domain of “digitalization of teaching and learning in TVET”. Through the examination of co-authorship networks among publications, several overarching trends and potential influences shaping collaborative efforts in this field are revealed. The network displays ten clear clusters of collaborating countries, indicating the prevalence of regional research collaborations. The cluster details are in Table 6. These clusters provide insights into the geographical distribution of collaborative research efforts in the field, highlighting the diverse and dynamic nature of international partnerships and influences within the TVET digitalization domain.

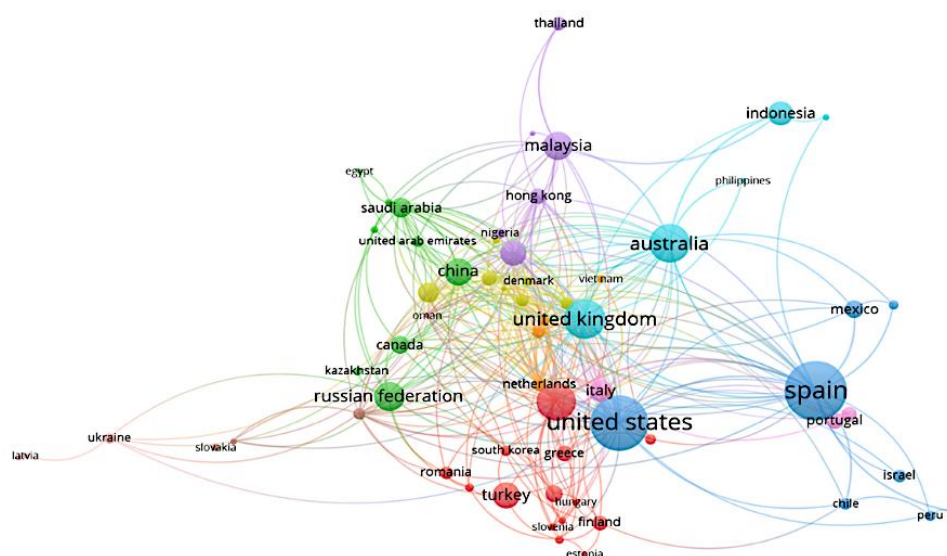


Figure 6. Co-authorship clusters by country

Table 6. Clusters of co-authorship by country

Cluster	Country
Cluster 1 (red)	Austria, Croatia, Estonia, Finland, Germany, Greece, Hungary, Ireland, Romania, Serbia, Slovenia, South Korea, Sweden, and Turkey.
Cluster 2 (green)	Canada, China, Egypt, Jordan, Kazakhstan, Pakistan, Russian Federation, Saudi Arabia, and United Arab Emirates.
Cluster 3 (blue)	Spain, Chile, Colombia, Ecuador, Israel, Mexico, Peru, and the United States.
Cluster 4 (yellow)	Denmark, India, Cyprus, New Zealand, Norway, Singapore, and Taiwan.
Cluster 5 (purple)	Malaysia, Japan, Ghana, Hong Kong, Nigeria, South Africa, and Thailand.
Cluster 6 (light blue)	Australia, Indonesia, Iran, the Philippines, and the United Kingdom.
Cluster 7 (orange)	Belgium, France, Netherlands, Switzerland, and Vietnam.
Cluster 8 (brown)	Czech Republic, Oman, Poland, and Slovakia.
Cluster 9 (pink)	Portugal, Brazil, and Italy.
Cluster 10 (light brown)	Latvia, Lithuania, and Ukraine.

Analyzing the dataset reveals distinct clusters of countries based on their research output, citation impact, and collaborative strength. Firstly, countries such as Spain, the United States, and the United Kingdom emerge as leaders in research output and citation impact. Spain leads in research output with 177 documents, while the United States gathers the highest citation impact with 2,592 citations. Additionally, the United Kingdom demonstrates notable collaborative strength with a total link strength of 62, indicating robust collaborative networks within the field.

Secondly, another cluster comprises countries like Australia and Germany, showcasing a balance between research output and citation impact. Australia, with 98 documents and 1,813 citations, and Germany, with 91 documents and 1,524 citations, exemplify this trend. These countries demonstrate the ability to produce high-quality research with significant influence within the TVET digitalization domain. Furthermore, the dataset highlights countries with moderate research output and high citation impact, such as Saudi Arabia. Despite having 38 documents, Saudi Arabia accumulates 1,106 citations, indicating impactful research contributions despite a relatively lower research output. This underscores the quality and relevance of research spreading from these regions.

Lastly, Figure 7 displays that the analysis reveals emerging trends in regional collaborations, with countries like Spain fostering strong ties, as visualized by the thickness of network lines with Latin American nations and Germany engaging in close collaborations with Switzerland. Moreover, countries like Taiwan and Switzerland demonstrate emerging roles in facilitating international research partnerships despite their lower research outputs. Overall, these insights strengthen the diverse and dynamic landscape of research collaboration in TVET digitalization. This emphasizes the importance of fostering international partnerships and leveraging strengths across regions to advance knowledge and innovation.

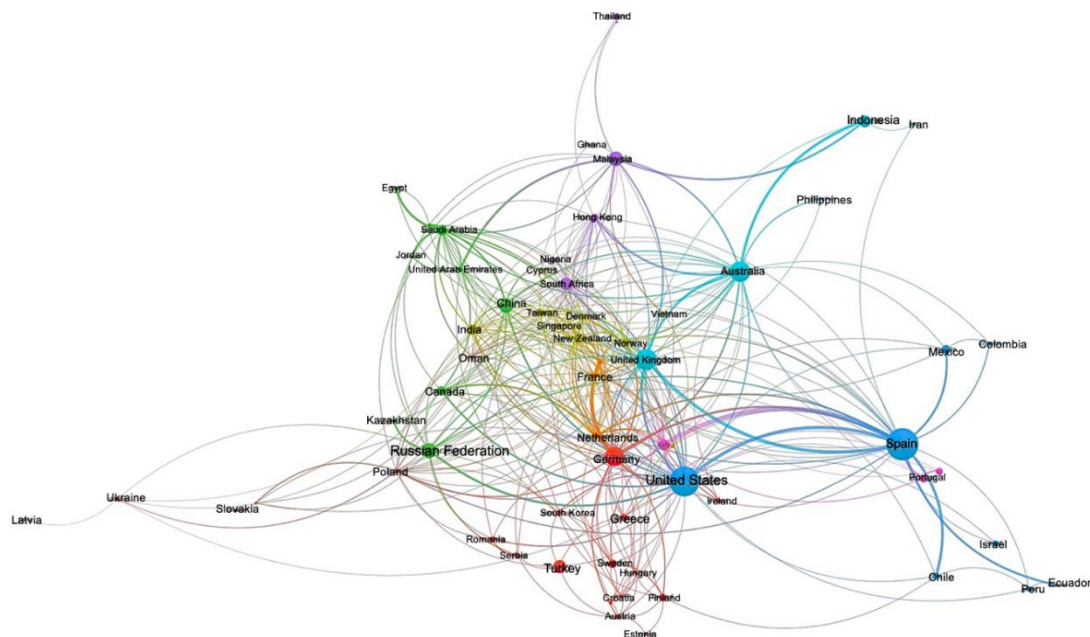


Figure 7. Co-authorship by country fostering strong ties visualized by the thickness of network lines

3.7. Citation of article's density by country

The map in Figure 8 reveals a density of citations by country for the research related to digitalization in TVET. Countries shaded lighter on the map are host researchers who produce highly cited works, and countries with darker shades on the map might indicate countries with lower research output or citation impact in this domain.

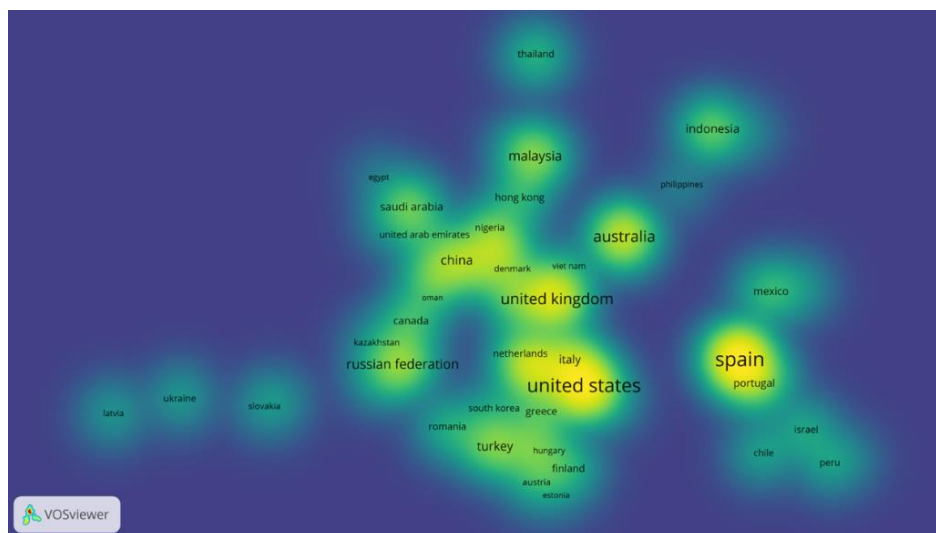


Figure 8. Citation of article's density by country

Referring to Table 7, the analysis of article density by country based on the number of documents, citations, and total link strength reveals notable trends within the field. Spain leads with 177 publications, indicating a substantial research output, while the United States demonstrates high citation numbers despite fewer documents, with 2,592 citations underscoring the impact of its research. The United Kingdom follows closely with 101 documents and 2,231 citations, reflecting a significant research presence and impact. Australia and Germany exhibit solid contributions with 98 and 91 documents, respectively, each accompanied by noteworthy citation counts. Saudi Arabia stands out for its considerable citation count (1,106) despite fewer documents (38), indicating impactful research originating from the region. Hong Kong, Taiwan, and Italy display moderate research activity and impact, while South Africa showcases a substantial contribution to the field with 51 documents and 762 citations. These findings emphasize the varying degrees of research activity and impact across different countries, highlighting the diverse global landscape of research in the field of digitalization of teaching and learning in TVET.

Table 7. Number of documents, citations, and total link strength by country

Country	Number of documents	Citations	Total link strength
Spain	177	2817	72
United States	160	2592	71
United Kingdom	101	2231	62
Australia	98	1813	54
Germany	91	1524	52
Saudi Arabia	38	1106	38
Hong Kong	26	874	27
Taiwan	25	859	26
Italy	44	780	45
South Africa	51	762	29

This prominence comes from various factors. Firstly, established research communities in nations with rich TVET and digitalization research tend to boast a larger pool of researchers generating high-quality outputs. Secondly, well-funded universities and research centers often attract skilled researchers and produce impactful publications. Thirdly, countries actively exploring crucial aspects of the field, such as specific technologies or pedagogical methods, may witness higher citation rates due to the relevance of their work.

These trends have implications for the field. The map aids in pinpointing countries with robust research communities and expertise in specific TVET digitalization areas. Countries with lower citation density can benefit from collaborating with research leaders to enhance capacity and knowledge sharing. Hence, highlighting less-concentrated research areas encourages the exploration of new directions and perspectives. Future research can explore comparative studies to analyze research strengths and weaknesses across countries, informing strategies for capacity building and knowledge exchange. Additionally, international collaborations can attach diverse expertise to address complex TVET digitalization challenges while establishing robust international networks that facilitate communication, collaboration, and knowledge exchange across borders.

4. CONCLUSION

The research reveals a consistent upward trend in publications focusing on the digitalization of teaching and learning in TVET from 2015 to 2023, indicating a notable surge in research engagement and interest in digitalization within vocational education. This trend is driven by genuine expansions in research efforts, technological advancements in digitalization, and emerging themes encouraging the exploration of digital learning in TVET. Moreover, the equitable distribution of publications among authors signifies a collaborative research spirit despite occasional fluctuations in publication rates. Visual representations of network maps reveal thematic clusters centered around digital competencies, diverse digital learning modalities, and pedagogical innovation. This underscore shifts in teaching approaches driven by technological progress. Understanding citation density patterns can inform capacity-building and collaboration strategies, suggesting potential research directions. This includes comparative studies, fostering international collaborations, and establishing global standards to enhance digitalization initiatives in TVET systems worldwide, promoting inclusive, innovative approaches to vocational education.

In conclusion, the trend in publications on the Digitalization of teaching and learning in TVET emphasizes an increasing focus on investigating digitalization within vocational education and training. The balanced dissemination of publications among top authors demonstrates a cooperative research environment and sustained scholarly activity within the field. In addition, the fluctuations observed in publication rates suggest ongoing exploration of emerging themes and evolving research priorities. Future research efforts may prioritize investigating new trends, addressing concerns of equity and accessibility, and further exploring the impacts of digital tools on teaching and learning outcomes. Accordingly, these trends strengthen the dynamic nature of the field and the potential for continual innovation and enhancement in vocational education practices through digitalization.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Norazreen Othman	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Marlissa Omar	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mohamad Sattar Rasul	✓	✓		✓			✓			✓	✓	✓		✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the finding of this study were retrieved from the Scopus database. All source documents are accessible via Scopus (www.scopus.com) by users with the appropriate institutional or individual access.

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BIOGRAPHIES OF AUTHORS



Norazreen Othman     is a vocational training officer at Department of Skills Development, Ministry of Human Resources. She is also a professional technologist recognized by Malaysia Board of Technologists (MBOT). She graduated from Universiti Sains Malaysia in electronics engineering and holds a master of science in information, decision and automation from University of La Rochelle, France. Currently, she is pursuing her PhD study in technical and vocational education and training (TVET) at Faculty of Education, Universiti Kebangsaan Malaysia and her research interests are in the field of digitalization in TVET. She can be contacted at email: p131319@siswa.ukm.edu.my.



Marlissa Omar     is a senior lecturer at centre for STEM enculturation, Faculty of Education, Universiti Kebangsaan Malaysia. She obtained her doctor of philosophy in technical and vocational education training (TVET) from Universiti Teknologi Malaysia (UTM). Besides teaching, she is actively involved in research activities. Her current research interests include vocational education, digitization in TVET, mobile apps in TVET education, and other issues in TVET education. She can be contacted at email: marlissa@ukm.edu.my.



Mohamad Sattar Rasul     is a professor at centre for STEM enculturation, Faculty of Education, Universiti Kebangsaan Malaysia. He obtained his PhD and M.Sc. in (industrial engineering and systems) (Universiti Putra Malaysia), bachelor of technology with education (mechanical engineering), diploma in mechanical engineering (Universiti Teknologi Malaysia). At the university level, he is the professor in TVET and STEM Education and currently being appointed as chairman of STEM enculturation studies center. His research area includes TVET policy and curriculum, quality assurance, qualification and skills certification system, career development, engineering, and STEM education. He can be contacted at email: drsattar@ukm.edu.my.